2021 NASA Small Spacecraft Virtual Forum
March - May 2021

Executive Summary

The 2021 National Aeronautics and Space Administration (NASA) SmallSat Virtual Forum brought scientists, managers, and engineers together to share challenges, lessons learned, and best practices regarding the formulation and execution of SmallSat missions. The forum consisted of five meetings, including an introductory meeting (Day 0) to share the SmallSat perspectives of the various NASA directorates, divisions, and centers. The remaining four meetings (Days 1-4) were dedicated to interactive open-forum workshop sessions of individual discipline-focused groups with an average participation of 33 per individual group. The results from Days 1-4 are summarized below.

On Day 1, the workshop sessions focused on the proposal phase and Pre-Phase A. Workshop participants strongly agreed there are three contributing factors for a successful project: a sound management plan, an understanding of the schedule and cost reserves, and careful evaluation of internal processes. They also identified four major project management challenges: (1) confusion about how NASA views risk and cost margins in SmallSat/CubeSat proposals, (2) a lack of publicly available cost models for Class D missions, (3) difficulty in identifying where to take 'extra' risks in the proposal, and (4) organizational structures that complicate staffing efforts for proposal development.

Clear definition of science goals and objectives is key to determine whether a mission is implementable as a SmallSat. These definitions help the science team and systems engineers to plan a mission that achieves compelling science, given the limitations of state-of-the-art technology for payload and spacecraft bus systems. Industry is constantly improving capabilities that could enable new missions, but this information may take time to reach potential Principal Investigators (PIs). NASA could facilitate information exchange by providing a central repository that contains the information in a standard format. In addition, the SmallSat community could benefit from NASA-provided proposal examples or proposal templates to enhance the quality of submitted proposals. The examples and templates would also help organizations without access to NASA center resources or experienced personnel to understand how to produce a winning proposal—potentially enabling new organizations to compete.

In terms of Safety and Mission Assurance (SMA), projects classified as Class D and below can be much more challenging than projects at Class C and above because the team will have to rely on focused understanding and management of risks and engineering judgment instead of defined, traditional practices. SMA sessions identified the need for NASA-provided resources to help projects with risk management. Missions can also benefit from available tools when preparing proposals, but these tools are not well advertised. For example, NASA centers have developed internal capabilities such as SmallSat design laboratories, but information about these capabilities is not readily available to the public. Workshop participants suggested that NASA sponsor a central location to promote these tools and capabilities.

Workshop sessions on Day 2 focused on project development cycle phases A, B, and C. Workshop participants tended to favor the two-step Phase A mission implementation process for SmallSats if: (1) the first step was simplified to reduce the number of resources needed and increase participation, and (2) the second step was adequately funded to ensure proper mission formulation. In addition, the group identified a need for NASA to establish a PI forum to encourage knowledge sharing in the SmallSat community.

Tailoring of documents is common for SmallSat missions and workshop participants identified a minimum set of required project-level documents: a master schedule, project plan, interface control documents (ICDs), and requirements. Reviews and configuration management processes should also be tailored to reduce the burden on SmallSat teams. The best solution may vary among projects and should be determined by considering a project's schedule, budget, team size, and risk posture. Complete and concise documentation helps guide the team, especially when staffing changes occur. Tailoring of requirements management is also typical with projects carrying Level 1 and Level 2 requirements, but lower-level requirements are handled differently depending on the mission. Often, subsystem leads develop requirements based on Level 2 requirements. Ideally, a subsystem lead should construct a specific set of comprehensive requirements, but most projects seem to carry only key requirements at the subsystem level.

The commercial market plays an important part in NASA SmallSat missions, but the market is still evolving, and multiple projects reported challenges and problems related to use of commercial products. Defective product deliveries, evolving ICDs, and significant schedule delays were among the top three challenges. Projects have also experienced negative changes in the quality and performance of commercial off-the-shelf (COTS) components and subsystems sourced from previously successful suppliers. To help mitigate these risks, projects can request an engineering unit or similar setup to be delivered for testing to the project team ahead of time.

Finding launch opportunities is a challenge for SmallSat missions, since they often receive the manifest (including testing requirements) at a late stage in the SmallSat development process. This challenge is even greater for missions outside of Low Earth Orbit (LEO) that also must meet orbital debris requirements. Late manifest increases risk for mission success, but there are other aspects that could involve considerable risk and that teams may need help to identify and track. For example, CubeSat PIs often struggle to define a reasonable approach for managing and reporting risk, as well as determining mitigation expectations for risks. Many SmallSat/CubeSat missions could benefit if NASA provided resources to help projects with risk management.

Day 3 sessions targeted activities and lessons learned during system assembly, integration and test (I&T), and launch. Work undertaken in advance by the project manager (PM), systems engineer (SE), and technical leads can lay the groundwork to mitigate issues during this phase. The PM must manage schedule, budget, risk, and personnel resources to tackle the "unknown unknowns." SmallSats often have strict delivery timelines, and the PM should strive to mitigate team members' fatigue and maintain morale—including backfilling technical roles as needed. When planning the schedule, the PM should budget adequate time for testing (e.g., double the expected time) to allow for inevitable delays.

SE challenges frequently involve management and communication of risks among various mission stakeholders. The SE team, often composed of a single team member, should fully understand the top-level requirements to inform descopes. Missions should also test interfaces as early and as often as possible since documentation and models are not always correct. Sufficient time should be allocated for system-level testing to enable the team to react to issues and determine appropriate penalty testing.

I&T planning for SmallSat missions that are managed according to NASA Procedural Requirement (NPR) 7120.5 differs from that for missions adhering to NPR, 7120.8 ("Do-No-Harm," or Institutional-Best-Practices projects)—especially with respect to the level of documentation, rigor of testing, descope options, workforce planning, and type of test facilities employed. Test teams for the 7120.8-governed missions tend to be smaller and team members may perform multiple roles including quality assurance; therefore, it is useful to involve experienced personnel who can make calculated decisions based on risk posture. NASA could benefit greatly from standardizing I&T and SMA processes for Class D missions since each institution tends to follow its own practices and the level of tailoring is not consistent.

Design, analysis, and testing need to incorporate worst-case environments, including those encountered before launch such as specific environmental tests and transportation. For example, a deployment test under gravity can be the worst loading condition for a deployable in comparison to conditions encountered in a low-gravity environment. Testing should be as flight-like as possible (even for subsystem-only tests). Thermal vacuum (TVAC) testing should be conducted using as much of the full system as possible. During testing, projects should capture as much information as possible, including important housekeeping data to identify performance trends and diagnose issues during testing and on orbit. Usually, the most important product generated by a satellite is its science data, but housekeeping data plays an important role for monitoring, diagnosing, and fixing spacecraft issues, should the need arise after launch. It is useful to include as much summary data in bit-flags as possible if all housekeeping data cannot be downlinked due to mission limitations. It is also beneficial to record as much data as possible during ground testing, since this ground test data can assist in troubleshooting on-orbit anomalies.

Effective Phase D ground system testing requires adequate equipment, knowledge, and resources to replicate the operational environment. Government, commercial, and academic organizations all provide ground system (GS) capabilities and services, but these services are diverse, awareness of such services is limited (which can impact mission planning), and the services are sometimes challenging to learn about and implement.

Workshop sessions on Day 4 focused on mission operations, sustainment, and closeout. Establishing the first contact and successful communications remain a major challenge for many SmallSat missions. Best practices to mitigate communications issues include designing the radio to turn on automatically without receiving a signal from the ground, carrying backup communication systems, planning for access to backup ground stations, and practicing commissioning activities with both primary and backup systems ahead of time. Initial contact can be more challenging for higher frequency radios, which often require pointing control.

Lessons learned that increase likelihood of SmallSat mission success include the addition of simple sensors including diodes and cameras, which help identify, diagnose, and mitigate anomalies. Another potential mission-saving practice is to implement a flexible design that allows operators to request more detailed telemetry for each subsystem, if needed for verification or fault detection. In addition, carrying out regular system reboots can help clear issues in the avionics.

While technical and programmatic issues still exist, CubeSat/SmallSat capabilities are constantly improving, and it is becoming more common for SmallSat missions to remain operational beyond their mission lifetimes. Options to receive additional Phase E funding vary greatly amongst projects and divisions at NASA and clear guidance and a responsive process are urgently required. Likewise, ready access to funding for Phase F activities is required to optimize the returns from missions.

Another common challenge PIs face involves processing, storing, and sharing of mission data. Guidance from NASA on data standards and the implementation of best practices regarding data processing, storage, and sharing (along with templates and examples) would benefit SmallSat missions. Leveraging commercial cloud solutions for data storage and processing creates major efficiencies, particularly for collaboration and sharing of data; however, some program restrictions within NASA prohibit these options.

The NASA SmallSat community is a large group of passionate and enthusiastic scientists, managers, and engineers reimagining ways to reveal the Universe's greatest's secrets utilizing this disruptive platform, but each project team cannot operate in isolation. This forum highlighted the importance of sharing challenges, lessons learned, and best practices across missions. Participants encouraged NASA to continue its support and provide platforms for community members to learn from each other, and suggested the Agency create a SmallSat mentoring program and institute a regular PI forum. Workshop participants also gained awareness of industry products and services, including user experiences—knowledge that will enrich the NASA SmallSat community and enable future mission success.